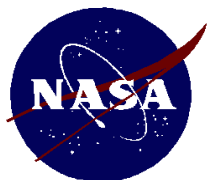
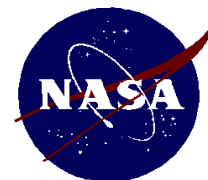


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NEWS

Two More Satellite Breakups Detected

P. Anz-Meador

The third fragmentation event of the year 2001 occurred on or about 29 April with the fragmentation of the Russian *Cosmos 1701* spacecraft. The NASA Johnson Space Center's Orbital Debris Program Office was notified by the US Space Command's (USSPACECOM) Space Defense Operations Center (SPADOC) of the assessed fragmentation on 1 May 2001. Ten (10) large debris were tracked by the USSPACECOM Space Surveillance Network (SSN) as of that date; as of 30 May 2001, no debris objects had entered the Space Control Center's (SCC) catalogue. *Cosmos 1701* (Satellite Number 16235, International Designator 1985-105A) was in an orbit of 85 km by 25,570 km with an inclination of 62.9 degrees at the time of the event. While this event represents the 17th known breakup of a *Cosmos* 862-class payload since the first event in 1977, this event is dissimilar to all preceding

events. Assessed cause of the *Cosmos 1701* fragmentation was aerodynamic loading due to the low perigee of the vehicle, rather than the deliberate destruction of the vehicle by an on-board explosive system.

Cosmos 1701 was an *Oko*-class vehicle. These vehicles perform missile launch early warning duties in orbits very similar to the Russian *Molniya* communications payloads. The three-axis stabilized vehicle is cylindrical in shape with two solar array panels and an erectable sun shade for the primary on-board sensor system. Dimensions of the cylinder are approximately 2 m in diameter and 1.7 m in length; dry mass is on the order of 1250 kg.

An analysis of the event, conducted the day the Orbital Debris Program Office was notified of the fragmentation, indicates that the long-term environmental consequences are minimal, as the parent object was in a catastrophic decay from the original *Molniya*-

type orbit. This lessens the spatial density in low Earth orbit because of the large eccentricity and low perigee of the vehicle's orbit.

The second breakup event of the quarter took place about 16 June and involved a Russian Proton K Block DM ullage motor, International Designator 1991-025G, Satellite Number 21226. The SSN detected as many as 100 debris in orbits similar to that of the parent object, which was 300 km by 18,960 km with an inclination of 64.5 degrees.

This was the 24th event of this type identified since 1984 (see Orbital Debris Quarterly News, January 2001, for the previous breakup). The breakups of the ~55 kg objects are assessed to be related to the presence of residual propellants. The problem was recognized in the early 1990's, and no Block DM ullage motor launched since 1996 is known to have experienced a fragmentation, in part due to design and operational changes. ❖

Joseph P. Loftus Retires from NASA

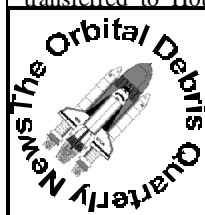
After an exceptionally distinguished career of 47 years service to the US Government, including 41 years on behalf of NASA, Joseph P. Loftus, Jr., retired on 30 April. Recently best known as the godfather of the NASA orbital debris program, Joe's contributions to the US space program date back to the US Air Force's original man-in-space program, including Dynasoar. As an Air Force officer, he was transferred to Houston in 1961 to assist the

fledgling Mercury program, where he was responsible for defining the crew accommodations and the crew control and display systems in the Mercury and, then later, Apollo spacecraft. Under a special task force effort, he led the design of the systems to extend the lunar landing mission stay time from 24 to 72 hours and the complementary extension of the total mission duration of the orbiting command and service modules from 9 to 12 days. As the

NASA human space flight program matured and evolved into the Space Shuttle and Space Station eras, Joe helped lead the way with both his technical and managerial expertise, including his tenure as Assistant Director (Plans) of the Lyndon B. Johnson Space Center.

During 1977-1979 Joe was instrumental in bringing the issue of orbital debris to the attention of senior NASA management. His

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NEWS

Joseph P. Loftus Retires from NASA, Continued

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efforts were rewarded in October 1979 when NASA Headquarters provided the first official funding for orbital debris research, later leading to the establishment of the Orbital Debris Program Office. Joe remained an active participant in the program until his retirement, culminating in his support to the US role in monitoring the deorbiting of the Russian space

station Mir. Joe served as a valuable ambassador of NASA to the national and international aerospace communities, including the IAF, IAA, and the United Nations, and is particularly well-known for his work with electrodynamic tethers, the geosynchronous debris environment, and orbital debris mitigation policies.

Twice the recipient of the NASA Exceptional Service Medal, upon his retirement

Joe was awarded the NASA Distinguished Service Medal, along with several other recognitions of his extensive contributions to NASA. His accomplishments not only are reflected in the great history of NASA but also will be a part of its future through the succeeding generations of scientists and engineers whom he has so powerfully and positively influenced. ♦

Hubble Space Telescope Solar Array Hypervelocity Impact Tests

R. Burt and E. Christiansen

As part of NASA's effort to characterize and evaluate the Meteoroid and Orbital Debris (M/OD) environment in low Earth orbit (LEO), the Johnson Space Center Hypervelocity Impact Technology Facility (HITF) conducted hypervelocity impact (HVI) tests on the Hubble Space Telescope (HST) Solar Array Cells.^{1,2} The detailed results of that test program are provided in JSC technical report 28307 titled *Hypervelocity Impact Tests on Hubble Space Telescope (HST) Solar Array Cells*.

In a four-year period of operation, the HST Solar Arrays are estimated to be impacted by approximately 40,000 particles greater than 10 microns, of which several hundred will perforate the arrays.³ By conducting HVI tests with known particles, hypervelocity impact damage characteristics of the solar cells and their correlation to particle size can be determined. With this data, on-orbit impact particle parameters (size, velocity, angle, and density) can be more accurately defined. This allows a determination of whether the impactor was a naturally occurring meteoroid or man-made orbital debris and

validates the existing M/OD environment.

The HST Solar Array Cells consist of three main layers: the Photo Cell composed of a CMX glass front face covering the silicon solar cell; the RTV Adhesive Layer; and the Support Layer, a composite structure on glass fiber, Kapton, Adhesive, and a Silver Mesh. This configuration is shown in Figure 1. Three specimens were tested and each consisted of two photocells; only one cell was impacted during each HVI test. The estimated areal density (mass per unit area) of the test specimens is 0.1527 grams per square centimeter.

The Hypervelocity Impact Test Facility and White Sands Test Facility 0.17" caliber two-stage light gas gun were used for this test program. A total of five tests were conducted with Al 2017-T4 spherical projectiles ranging in size from 0.4 mm to 0.8 mm. Each specimen was normally impacted (0°) on the solar cell glass side at approximately 7.0 km/s. Characteristic damage seen from these tests is shown in Figure 2 and Figure 3.

All test articles exhibited similar HVI characteristics that can be differentiated by

layer. The photo cell layers (glass and metal) exhibit the characteristics of an impact crater with the outer glass layer showing surface cracking and 2x to 3x larger craters (measured at the surface) than the through hole in the RTV layer. The support layer (epoxy resin and mesh laminate) had impact hole sizes smaller than the photocell layer and larger than the RTV layer. The support layer exhibited slight delamination.

Figure 4 shows the relation between the through hole diameter (D_3) and Projectile Kinetic Energy. Edge impacts typically result in greater damage to the target than impacts far from the edges. Using the data from non-edge impacts, a through hole diameter prediction equation was developed and is given below:

$$D_3 = 0.926 KE_n^{1/3} - 0.169 \quad (1)$$

Where D_3 is the diameter of the through hole (mm) and KE_n is the normal component of the projectile kinetic energy (J). Figure 4 illustrates the impact data and correlation using Equation 1. Equation 2 can be used to estimate projectile

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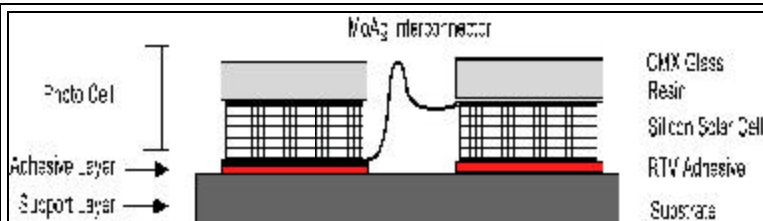


Figure 1. Hubble Space Telescope Solar Cell Cross-section

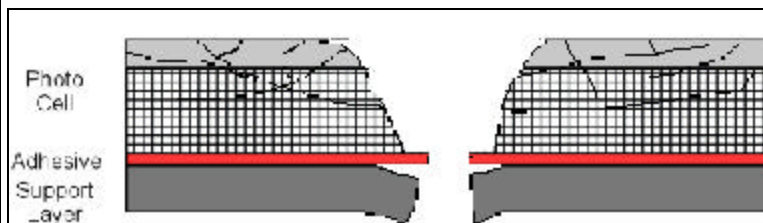


Figure 3. Characteristic Solar Cell Impact Damage (cross-section)

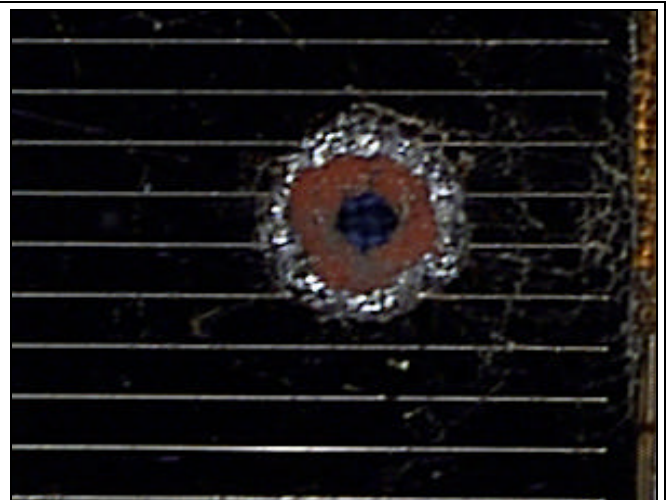


Figure 2. Characteristic Solar Cell Impact Damage (front view)



NEWS

Hubble Space Telescope Solar Array Hypervelocity Impact Tests, Cont'd

(Continued from page 2)

diameter, d (cm), resulting in a given solar cell hole diameter, D_3 (mm). This form of the equation is useful in BUMPER code predictions.

$$d = 0.169(D_3 + 0.169)\rho^{-1/3} V^{-2/3} \cos^{-2/3} \theta \quad (2)$$

Where ρ is projectile density (g/cm^3), V is impact speed (km/s), and θ is the impact angle measured from the target normal (deg).

A more detailed description of the test programs is written in JSC technical report 28307 titled *Hypervelocity Impact Tests on Hubble Space Telescope (HST) Solar Array Cells*. Further information of HVI testing on the HST Solar Arrays is available from the European Space Agency reports, for instance "Meteoroid and Debris Flux Assessment on Oriented Surfaces, Application to Eureca and HST Solar" (Continued on page 10)

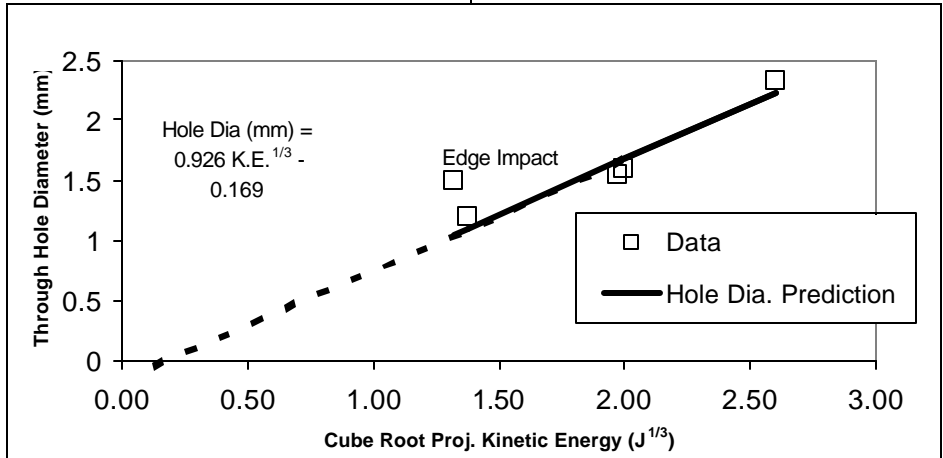


Figure 4. Through Hole Diameter vs. Cube Root of Projectile Kinetic Energy Chart

Meteoroid and Orbital Debris Impact Analysis of Returned International Space Station Hardware

J. Hyde, E. Christiansen, and R. Bernhard

Three hypervelocity impacts were observed on the cylinder region of the MPLM1 after STS-102/5A.1. The impacts caused only superficial damage to the outer bumper. The most significant of the three was a 1.44 mm diameter hole in the 0.8 mm thick aluminum bumper of the Meteoroid Debris Protection System (MDPS). It was determined from Scanning Electron Microscope (SEM) analysis that the hole was caused by orbital debris, a fragment of spacecraft paint approximately 0.5 mm in diameter. The other two impacts produced craters in the MDPS bumper. There was no observed damage to the MLI thermal blanket underneath

or to the MPLM1 pressure wall.

A BUMPER code analysis was performed with post-flight attitude data to determine the regions of the MPLM1 cylinder that were most likely to be hit by meteoroid and orbital debris particles in the general size ranges of the observed impacts. All three impacts were near the region with the highest risk. The analysis indicated that the bumper had a 1 in 5 chance of being perforated during the 6 days of exposure and that orbital debris was most likely to cause the penetration.

Five hypervelocity impacts were detected on the aluminum housing of an EVA Safety Tether returned on STS-97/4A after nearly two

years on orbit. The largest impact, a 0.83 mm diameter by 0.45 mm deep crater, was caused by an estimated 0.3 mm diameter orbital debris particle. SEM analysis of crater residue revealed an abundance of silicon, indicating that the impactor may have originated from a glass window or a solar panel. The craters did not effect the on-orbit operation of the tether or prevent its reuse.

Probability calculations using post-flight data indicated a 1 in 114 chance that the tether housing would be impacted by a 0.3 mm diameter projectile during the 2-year exposure period, an impact risk of less than 1%. ♦

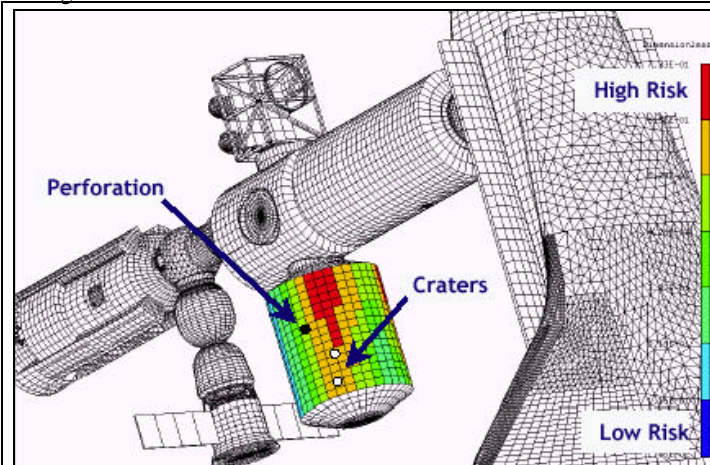


Figure 1. MPLM bumper perforation risk plot, with impact locations noted.



Figure 2. Inspection of 21.2 cm (8.4 in) long tether housing.



NEWS

GOES 2 and Landsat 4 Retired

Two long-lived US spacecraft were retired during May-June and placed in disposal orbits to reduce collision risks with other resident space objects. One was placed in a very high altitude storage orbit away from operational spacecraft, while the other was placed in a lower altitude orbit to accelerate its return to Earth.

The GOES 2 spacecraft, launched 16 June 1977, provided valuable meteorological services for both the Western and Eastern Hemispheres for many years. Although the satellite had out-lived its 3-year design lifetime many times over and was built before policies for geosynchronous (GEO) spacecraft disposal into higher altitude storage orbits had been established, for several years responsible U.S. authorities had been carefully monitoring the systems and propellant supply of the GOES 2 spacecraft to permit the transfer to a

storage orbit.

During the first five days of May, commands from the Kokee Park Geophysical Observatory in Hawaii prompted GOES 2 to perform a series of maneuvers which raised the spacecraft out of the operational GEO regime, i. e., the region from 200 km above to 200 km below GEO (~35,785 km altitude). GOES 2 was left in a slightly eccentric orbit ranging approximately 200-300 km above GEO. The vehicle was successfully passivated and turned off on 5 May.

Meanwhile, in low Earth orbit (LEO) the nearly 19-year-old Landsat 4 spacecraft was nearing the end of its equally impressive extended mission. Launched on 16 July 1982 into a sun-synchronous orbit, Landsat 4 was designed for retrieval by a Space Shuttle in 1986. However, the decision not to launch Space Shuttles from Vandenberg Air Force

Base eliminated this option.

From its operational altitude near 700 km, Landsat 4 would likely remain in orbit for several decades before falling back to Earth. Therefore, in accordance with U.S. orbital debris mitigation standard practices, Landsat 4 was commanded to use its residual propellant to maneuver into a lower altitude disposal orbit from which reentry could be accomplished within 25 years. Maneuvers began in early June and by mid-June, Landsat 4 was in a nearly circular orbit near 590 km, greatly reducing the time the spacecraft will remain in orbit.

Landsat 5, launched in 1984 into an orbit similar to that of Landsat 4, is also rapidly approaching retirement. Planning is now underway to follow the lead of Landsat 4 and to transfer Landsat 5 to a shorter-lived disposal orbit. ❖



Project Reviews

Recent Enhancements to the EVOLVE Orbital Propagator

D. Hall

Recent enhancements of the orbital propagator used by NASA's EVOLVE model should help provide a more realistic and accurate assessment of the future debris environment. The need to project satellite trajectories into the future is fundamental to any orbital debris computer model. The EVOLVE *orbital propagator* accomplishes this task by accounting for the various perturbing forces acting on a satellite and calculating future orbital parameters. Perturbing forces include atmospheric drag, lunar and solar gravity, solar radiation pressure as well as the non-uniformity of Earth's gravitational field. The previous version of the EVOLVE propagator included all of these except solar radiation pressure, and employed many approximations to speed the calculation. Enhancements to the propagator were prompted by recent efforts to upgrade NASA's orbital debris models to include smaller debris particles as well as to calculate more realistic 3-dimensional debris distributions.

Developed some years ago when computers were considerably slower, the original EVOLVE 4.0 propagator required an efficient algorithm optimized for speed of calculation. Many approximations were employed to accomplish this objective. For instance, solar radiation pressure perturbations were neglected

completely. This was justified because EVOLVE 4.0 was designed to simulate the population of debris particles larger than 1 cm in size occupying low Earth orbit. Solar radiation pressure is generally a negligible perturbing force for such particles. However, recent efforts to extend NASA's debris models to consider particles as small as 1 mm and consider altitudes much higher than low-Earth orbit prompted the construction of a solar radiation pressure module for the propagator. This new module calculates orbital modifications caused by the force solar photons exert on satellites and debris. Accounting for the time that objects spend in Earth's shadow (where solar radiation pressure is reduced to zero) constitutes a significant complication in the calculation.

The previous EVOLVE propagator approximated atmospheric drag rates using a spherically symmetric, non-rotating model of Earth's atmosphere. While this idealization provides simple and computationally efficient estimates of drag rates, it neglects two known features of the terrestrial atmosphere: rotation and oblateness. First, the atmosphere tends to rotate along with the Earth (i.e., once per day), which can affect orbital drag rates. For instance, low-altitude satellites in prograde orbits (which travel in the same direction as the atmospheric rotation) experience significantly

less drag than retrograde satellites (which travel against the flow). Second, the Earth is not a perfect sphere but has an oblate figure: its polar radius is about 20 km smaller than its equatorial radius. The terrestrial atmosphere closely follows Earth's oblate figure, effectively reducing drag rates for satellites with perigee positions that occur over Earth's polar regions.

Deviations of Earth's gravity field from that of a perfect sphere also perturb satellite orbits. The dominant effect arises from the Earth's oblateness, given by the J_2 coefficient of the gravity field, and leads to the well-known precession of orbital planes and perigee positions. However, lesser but significant effects arise from J_3 and J_4 coefficients (not included in the original propagator). For instance, J_3 perturbations can lead to oscillations in perigee altitude and thereby periodically increase atmospheric drag rates significantly. The upgraded propagator includes J_2 , J_3 and J_4 orbital perturbations. In addition, for satellites in geosynchronous or near geosynchronous orbits, the upgraded version includes the resonant tesseral terms of Earth's gravity field $J_{2,2}$, $J_{3,1}$, $J_{3,3}$, $J_{4,2}$, and $J_{4,4}$. The gravity of the Sun and Moon also affect the orbits of artificial satellites, and the propagator has been enhanced to employ the second-order third-body perturba-

(Continued on page 5)



Project Reviews

Recent Enhancements to the EVOLVE Orbital Propagator, Cont'd

(Continued from page 4)

tion equations developed by Toshiya Hanada of Kyushu University. To speed this part of the computation, the propagator uses look-up tables of pre-calculated Sun and Moon positions.

Combined, these enhancements have proven to provide an improved ability to match the detailed orbital evolution observed for several long-lived satellites used as test cases in the

upgrade effort. The new propagator capabilities will allow the next generation of NASA orbital debris models to include particles as small as 1 mm orbiting anywhere from low-Earth orbit up to geo-synchronous orbit, and will serve as part of the effort to provide a more realistic 3 dimensional view of current and future orbital debris environments. However, the increased accuracy comes at a price — the upgraded

propagator requires about 12 times more computer time to project an orbit as compared to the old EVOLVE 4.0 propagator. Fortunately, computers are getting faster and faster every year. Using the latest generation of workstations, a 100-year EVOLVE orbital debris projection can still be done during a single night of computing. ♦

Overview of GEO Debris Observations Using the CCD Debris Telescope

K. Jarvis, J. Africano, P. Sydney, E. Stansbery, T. Thumm, K. Jorgensen, and M. Mulrooney

The National Aeronautics and Space Administration (NASA) has been using the Charged Coupled Device (CCD) Debris Telescope (CDT), a transportable 32-cm Schmidt telescope located near Cloudcroft, NM, to help characterize the debris environment in Geosynchronous Earth Orbit (GEO). The CDT system is capable of detecting 17th magnitude objects in a 20 second integration which corresponds to a ~0.6-meter diameter, 0.20 albedo object at 36,000 km. Objectives of this study will be accomplished by obtaining distributions in brightness, mean motions, inclination, ranges, and Right Ascension of Ascending Node (RAAN) of detected debris assuming a circular orbit. The size of an object is estimated, using an average albedo of 0.2.

The CDT is equipped with a SITe 512 X 512 CCD camera. The pixels are 24 microns square (12.5 arcseconds) resulting in a 1.7 by 1.7 degree field-of-view (fov). The CDT used a search strategy optimized to collect data at low

solar phase angle where satellites, including debris, should be brightest. By observing near the GEO belt, all uncontrolled objects will sooner or later pass through the fov. Specifically, the search strategy used by the CDT was to observe a strip of GEO space eight degrees tall, centered at minus five degrees declination (the GEO belt as viewed from Cloudcroft). This strip either leads or follows the Earth's shadow by about ten degrees. Orbits of uncontrolled GEO objects oscillate around the stable Laplacian plane, which has an inclination of seven-point-five degrees with respect to the equatorial plane. The telescope is pointed to a position in the sky (a search field) and parked during each exposure. Due to the Earth's rotation, the stars leave streaks in the east-west direction. Objects orbiting the Earth will appear as streaks or points depending on their altitude and inclination. The actual observing sequence consists of a series of four exposures taken of approximately the same field. Each exposure is 20 seconds in duration with a 15 second "dead time" between exposures used to read out the

CCD and to reposition the telescope. On average, 250 fields are collected per night, or 1000 individual images.

There were 58 days of data reduced for 1998, starting with Day Of Year (DOY) 60 and ending with DOY 353. An average of ~7.2 hours of data were gathered every night, totaling 10620 fields (with 4 frames per field). An object is either defined as being a correlated target (CT), i.e. one that can be identified with a tracked object in USSPACECOMs catalogue, or an uncorrelated target (UCT), an object that is not listed in the catalog. A total of 3982 CTs (unique per night-UPN) and 1006 UCTs were found, totaling 4988 objects with 20% of the total objects for the year being identified as UCTs. UPN indicates that regardless of how many frames within a night an object appeared in, it is counted only once. No comparisons were made between nights for the UCTs. A total of 30694 square degrees were observed. The detection roll-off in absolute magnitude for UCTs occurs around a size of 1.1 meters. See (Continued on page 6)

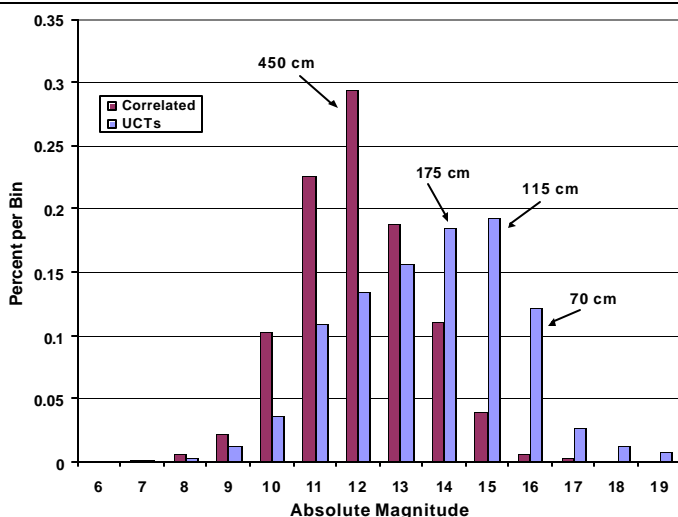


Figure 1. Absolute magnitude and derived size distribution.

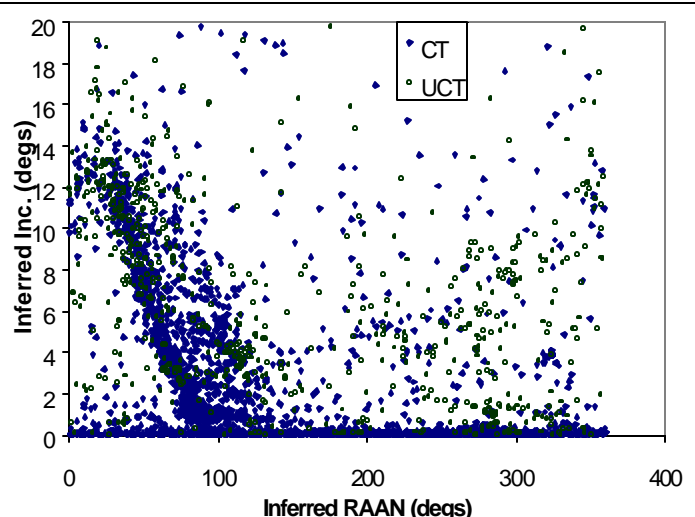


Figure 2. Inferred RAAN vs Inferred Inclination, 58 nights.



Project Reviews

Overview of GEO Debris Observations Using the CCD Debris Telescope , Cont'd

(Continued from page 5)

Fig. 1. Details regarding objects predicted to be in the fov but which were not seen in the frame ("nosees") were examined. The primary goal was to define whether the object's track was lost, or in some cases, limiting magnitude was the reason for its lack of presence in the fov. Several nosees could be removed from the count of 824 nosees for various reasons: seen on another night (therefore it's orbital elements are good), bad viewing conditions worsening detection limit, objects seen on the edge of the fov or objects with both ends of their track not fully in the fov and therefore no orbital data could be calculated, old epoch dates, and pointing error issues for a given night. In all, the number of nosees dropped to 115 due to removal from the nosee list based on the above conditions. Of the remaining 115 nosees, limiting magnitude is likely the prime factor for their lack of detection.

In many of the following analyses, an 11-night sample is used rather than the entire database of objects. This is in part due to the processing programs not providing certain needed information for the analyses desired. The processing programs will be modified to change this in the future. The 11-night sample has been compared against the complete data

set and has proven itself to be representative.

Due to the manner in which the search strategy is performed, objects may be seen in multiple fields within a night. When objects occur in adjoining fields, the correlation is apparent. When objects appear with several fields between the occurrences, the correlation is not apparent. In the 11-night sample, repeatability of non-station kept CTs within a night was found to be 30%. UCTs can be correlated to themselves within a night by means of plots of rates of change of RA and Dec. The UCT repeatability within a night for the 11-night sample shows that UCTs have an average repeatability of 9.5%. If this average repeatability is applied to the total number of UCTs seen for the year (1006), about 100 of the UCTs are repeat viewings within the same night that were not immediately apparent and could only be identified as repeats through the RA/Dec plots. This implies that the number of actual UPN UCTs for the year will be about 900.

The UCTs in GEO are fairly well distributed with inclination while the CTs peak at zero degrees. When inferred inclination with respect to inferred RAAN for CTs and UCTs are plotted, the distribution for CTs matches the catalog and UCTs are well distributed. See Fig.

2. Fig. 3 shows the inferred range versus inferred inclination distribution for CTs and UCTs. There is a "hard break" at about 14 degrees which is expected and related to the oscillation in the inclination as mentioned previously. The errors associated with inclination, range and RAAN have all been examined using the 11-night sample. Eccentricity has been included in the analysis as a circular orbit is assumed in the orbital elements calculations. The average inclination error of all objects is 0.03 degrees, with a standard deviation of 6.3 degrees. When objects with eccentricity greater than 0.04 are removed, the average inclination error is -0.2 degrees and the standard deviation is reduced to 1.6 degrees. The data shows that the inferred inclination is being under-determined for the largest inclinations. The range errors for the 11-night sample had an average error of 973 km and a standard deviation of 4103 km. After the high eccentricity objects were removed the range errors dropped to -23 km and 774 km, respectively. The largest RAAN errors seen are those objects with the smallest inclinations. The average RAAN error for all objects is 24 degrees and the standard deviation is 91 degrees. When only objects with inclinations greater than 1 degree are examined, the average RAAN error is 9 degrees and the standard deviation is 56 degrees. When the high eccentricity objects are removed, the average RAAN error is 9 degrees and the standard deviation is 99 degrees. A few objects have very large errors (> 50 degrees) and these are under investigation. It appears that these were objects observed for a very short period of time, viewed in only one or two frames. The shorter the observation time, the greater the errors will tend to be.

A better understanding of the orbital debris environment at GEO is essential if mitigation of the expansion of this environment can occur. The CDT is capable of detecting 17th magnitude objects (~0.6 m diameter, 0.20 albedo) located at 36,000km. Epoch dates of element sets need to be as recent as possible for accurate prediction and correlation of satellites. The assumption of a circular orbit generates inclinations that are consistently underdetermined. Inferred ranges for "true" GEOs have, on average, an error less than one percent. Inferred RAANs for inclinations of one degree or less show a great deal of scatter. The proportion of UCTs to CTs is in agreement with previous studies. Continued analyses of this and future datasets will help improve characterization and therefore, better understanding of the orbital debris environment at GEO. ❖

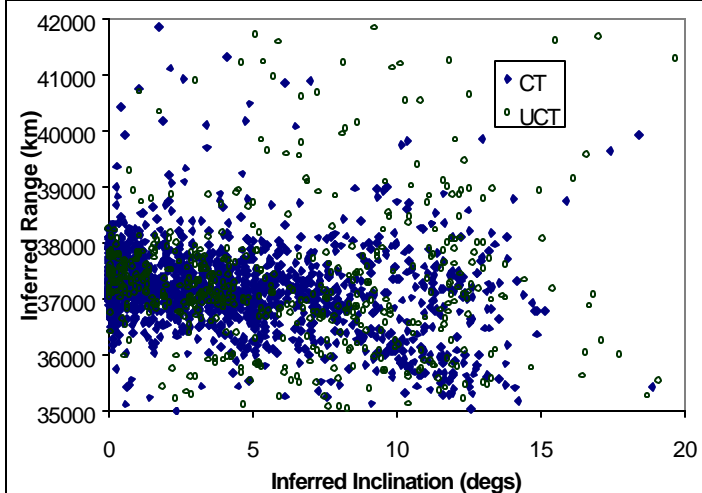
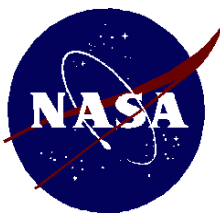
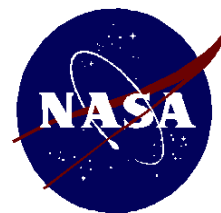


Figure 3. Inferred Inclination vs. Inferred Range, 58 nights



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Project Reviews

A Fragmentation Assessment of Legacy Delta Rocket Bodies

P. Anz-Meador

A recent review of the growth of the on-orbit population during the decade of the 90s indicated that one of the most severe fragmentations was that of the Nimbus 6 rocket body (R/B). This derelict Delta 2910 second stage, in orbit since 12 June 1975, fragmented on 1 May 1991 into 237 cataloged debris objects. Obviously this launch, Delta flight 111, occurred before the formal second stage passivation was introduced with Delta 156 in 1981. This raised, however, the question of if any other Deltas current on-orbit were still capable of fragmentation; this short article addresses that question.

Table 1 consists of those Delta rocket bodies, of any model, on orbit as of 31 January 2001. Herein, model refers to the actual manufacturer's model number of the stage, flight number is the Delta flight sequence number, *e.g.* 111, and deployment orbit type refers to either sun synchronous (SS), deep space (DS), or geosynchronous transfer orbit (GTO) disposition of the R/B. Two documents were used to code various R/B by passivation and stage fate. These are the Investigation of

Delta Second Stage On-Orbit Explosions (McDonnell Douglas MDC-H0047, April 1982) and the NASA History of On-Orbit Satellite Fragmentations, latest edition, respectively. The former reports not only whether passivation (venting) was performed, but also the residual propellant mass on board each R/B. Note that no *formal* venting was performed for these R/B; venting in the context of this table indicates a motor burn to propellant depletion during the course of orbit insertion and not the payload avoidance/passivation maneuver performed with Delta 156 and later flights. The latter document allows a coding by event type: a fragmentation or anomalous event. The Nimbus 7 R/B has experienced both types of events, while the GMS R/B was vented yet fragmented approximately 56 hours after launch. Several R/B which have fragmented are not included, *e.g.* the LANDSAT 1 R/B, because the debris piece allocated the R/B designation has decayed. For the purposes of this analysis, only those launches for which serendipitous venting was not performed are considered.

This culling leaves only seven stages on-orbit and unvented: the five N model stages, a

model 100 vehicle (Delta 91, NOAA 2 R/B), and a model 1000 vehicle (Delta 150, RCA-C R/B). The MDAC report indicates that Delta 91 has 187 lbm of oxidizer aboard, but only 5 lbm of fuel. As this is similar to the estimated residual fuel aboard the GTO missions, Delta 91 is not considered a likely candidate for a fragmentation. Delta 150 was launched 7 December 1979 in a failed GTO mission. Because of its mission profile's similarity to those GTO R/B which, effectively, performed a depletion burn in the course of normal orbit insertion, Delta 150 is also removed from consideration. Only the N model Deltas remain.

Several changes differentiate an N model second stage from the 100 (and later) series. Physically, the model N and 100 series were stressed for aerodynamic flight, while the 1000 series introduced the so-called "straight 8" configuration, *i.e.* a constant eight (8) foot diameter through enclosing the second stage in a fairing structure. The most obvious visual distinction is the series 1000's annular truss encircling the second stage. Less obvious was a change in motor from the N model's Aerojet

(Continued on page 8)

international designator	SSN cat. #	Delta model number	Delta flight number	launch date	inclination [deg]	apogee alt. [km]	perigee alt. [km]	deployment orbit type	payload
1968 - 69 B	3346	N	58	16 AUG 68	101.84	1466	1429	SS hi	ESSA 7
1968 - 114 B	3616	N	62	15 DEC 68	102.16	1470	1448	SS hi	ESSA 8
1969 - 16 B	3767	N	67	26 FEB 69	101.7	1499	1420	SS hi	ESSA 9
1970 - 8 C	4322	N-6	76	23 JAN 70	101.78	1479	1435	SS hi	ITOS 1/OSCAR 5
1970 - 106 B	4794	N-6	81	11 DEC 70	101.73	1481	1422	SS hi	NOAA 1
1972 - 82 C	6237	300	91	15 OCT 72	102.8	1466	917	SS hi	NOAA 2
1972 - 97 B	6306	900	93	11 DEC 72	99.84	1516	1101	SS mid	Nimbus 5
1973 - 86 B	6921	300	98	6 NOV 73	102.18	1578	1344	SS hi	NOAA 3
1975 - 4 B	7616	2910	107	22 JAN 75	97.83	780	708	SS lo	LANDSAT 2
1975 - 27 B	7735	1410	109	9 APR 75	114.97	850	783	SS lo	GOES 3
1975 - 52 B	7946	2910	111	12 JUN 75	99.7	1095	1027	SS mid	Nimbus 6
1975 - 72 B	8063	2913	113	9 AUG 75	89.21	2459	314	DS	COS-B
1975 - 77 B	8133	2914	114	27 AUG 75	25.31	1126	384	GTO	Symphonie 3
1976 - 77 B	9063	2310	126	29 JUL 76	101.16	1317	1163	SS hi	NOAA 5
1977 - 5 B	9786	2914	128	28 JAN 77	28.01	1237	613	GTO	NATO III-B
1977 - 48 B	10062	2914	131	16 JUN 77	28.42	1703	570	GTO	GOES B
1977 - 65 B	10144	2914	132	14 JUL 77	29.07	1771	516	GTO	GMS
1977 - 80 B	10295	2313	133	25 AUG 77	27.1	2077	871	GTO	SIRIO
1977 - 108 B	10490	2914	136	23 NOV 77	28.31	2389	486	GTO	Meteosat
1977 - 118 B	10517	2914	137	15 DEC 77	28.67	1842	478	GTO	Sakura
1978 - 26 C	10704	2910	139	5 MAR 78	98.44	619	542	SS lo	LANDSAT 3
1978 - 39 B	10793	2914	140	7 APR 78	28.23	1944	569	GTO	BSE
1978 - 44 B	10856	3914	141	11 MAY 78	27.95	3525	1568	GTO	OTS-2
1978 - 62 B	10954	2914	142	16 JUN 78	28.42	1627	551	GTO	GOES C
1978 - 98 B	11081	2910	145	24 OCT 78	99.41	968	926	SS lo	Nimbus 7
1979 - 101 B	11636	3914	150	7 DEC 79	28.22	2625	584	GTO (failure)	RCA-C
NASA Fragmentation Event					MDAC Report, No Vent				
NASA Anomalous Event					MDAC Report, Vent				



Project Reviews

A Fragmentation Assessment of Legacy Delta Rocket Bodies

(Continued from page 7)

AJ10-118 (Vanguard R/B heritage) to the 100 series' AJ10-118F (Titan Transtage heritage). An examination of all AJ10-118 powered Delta second stages to attain orbit indicates there are no fragmentation or anomalous events associated with any rocket body. Therefore, unvented N model second stages appear to present no fragmentation threat.

In summary, there appear to be no Delta second stages on-orbit capable of fragmenting. In the case of the model N vehicles, this may be due to a natural robustness of design. For later series models, serendipitous venting due to orbit insertion maneuvers appears to have passivated those vehicles which have not already fragmented. The propensity of series 100 and later stages to fragment may be connected with

engineering design changes required either by a change of engine, the change from an aerodynamic vehicle to a shrouded vehicle, or other factors as yet unidentified. Whatever the physical reason for fragmentations, the active program of passivation that began with Delta 156 has effectively ended the era of Delta fragmentations. ♦

Observations of Space Debris in Geosynchronous Orbit with the Michigan Schmidt

P. Seitzer

NASA is supporting an optical survey of space debris in Geosynchronous Earth Orbit (GEO) with the University of Michigan's Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory in Chile. This telescope (pictured in Figure 1) is of classical Schmidt design, with a 61 cm diameter aperture and a CCD detector. In a 5 second exposure the telescope can detect objects at GEO of fainter than magnitude 18.5, over a field of view 1.3 by 1.3 degrees with 2.3 arcsecond pixels. This facility is called MODEST (Michigan Orbital Debris Survey Telescope).

The survey began in February 2001, when over 1000 square degrees of sky were surveyed using a new technique optimized for detecting objects in geosynchronous orbit. The fundamental problem when observing such objects is that the stars, which are both the reference frame and the background, move with respect to GEO objects at 15 arcseconds/second due to the Earth's rotation. But one would also like to observe objects at GEO when they are at a maximum angle from the Sun: as close to 180 degrees away as possible. At this point the objects are at their brightest as seen from Earth.

With MODEST, the telescope tracks the stars at a point of maximum solar phase angle, while the detector tracks the GEO objects. This is done by shifting the charge on the CCD while the shutter is open, a technique known as TDI (Time Delay Integration). This technique is used in astronomy usually with the telescope parked with the drive off, and the charge motion is introduced to remove the apparent motion of the stars due to Earth rotation. But with MODEST, the technique is applied backwards: in order to track a point of maximum solar phase angle, the telescope tracks at sidereal rate and the effect of Earth rotation is removed using TDI. Thus the stars

appear as short streaks and GEO satellites appear as point sources. Observing in such a manner yields the greatest sensitivity to objects in geosynchronous orbit.

Figure 2 shows a sample 5 second exposure obtained in Chile with the Michigan Schmidt. The short streaks are stars, while three geostationary satellites are indicated. Each night over 700 such short exposures are obtained at a fixed declination spanning a continuous range in orbital longitude of over 100 degrees, all at the same solar phase angle. It takes about 5 minutes for a GEO object to drift across the telescope field of view: during this time 7 independent observations are obtained of each object producing measurements of an object's position, motion, and brightness.

MODEST observations will begin again this October and extend to the end of March 2002. During this time a minimum of 60 dark or gray nights will be dedicated to debris observations. Results will be presented as soon as they become available.

Collaborators include Roger Smith (CTIO), John Africano (Boeing), Kira Jorgensen (NASA/JSC), Dave Monet (USNO), Hugh Harris (USNO), Mark Matney (Lockheed-Martin), and Eugene Stansbery (NASA/JSC). ♦

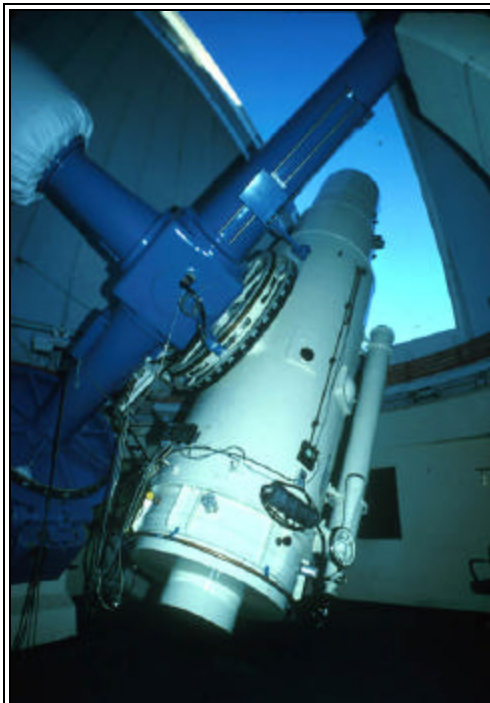
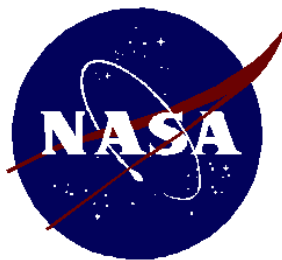


Fig. 1. The University of Michigan's 0.6/0.9-m Curtis Schmidt telescope at Cerro Tololo used for GEO orbital debris observations.

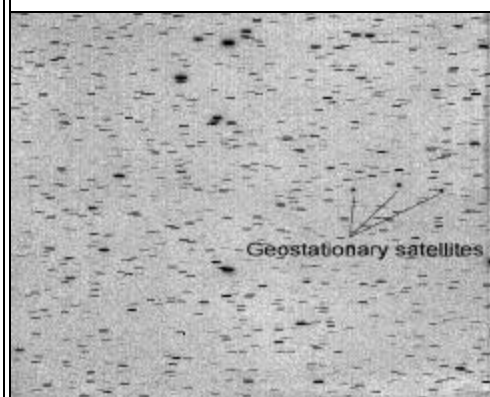


Fig. 2. Example of a 5 second exposure obtained with the Michigan Schmidt. Stars appear as short streaks due to charge shifting during the exposure, while GEO objects appear as point sources. 3 geostationary satellites are indicated.



Meeting Report

Orbital Debris Colloquium Held at NASA Headquarters

Representatives from each of the NASA centers and various contractors attended the Orbital Debris Colloquium held at NASA Headquarters in Washington, D.C. on April 25-26. The prime objective of the colloquium was to get everyone on the right track regarding NASA policies and the NASA Safety Standard (NSS) 1740.14. The meet was also an opportunity for each of the NASA centers and contractors to ask questions about the individual orbital debris mitigation guidelines. According to NASA Policy Directive (NPD) 8710.3, each NASA program/project is required to conduct a formal assessment "of debris generation potential and debris mitigation options". NSS 1740.14 provides the guidelines for performing this orbital debris assessment.

In addition to the policy and safety standard discussions, each of the NASA centers was given the opportunity to present the work being done at their center to address the issue of orbital debris. Talks were also given on both the Debris Assessment Software (DAS) and Object Reentry Survival Analysis Tool (ORSAT), as well as several reentry studies performed using these programs, including analyses of the Tropical Rainfall Measuring Mission (TRMM), Extreme Ultraviolet Explorer (EUVE), Genesis, and EOS Aqua spacecraft. The last portion of the meeting provided a time for open discussion on topics such as international programs, US interagency programs, environmental impact assessments, and trades between science payloads and orbital debris mitigation.

Though the two-day colloquium accomplished most of the meeting's objectives, still more remains to be discussed regarding the NASA safety policy and guidelines pertaining to orbital debris. One recommendation coming out of the Orbital Debris Colloquium was to provide additional technical information on the characteristics and capabilities of the ORSAT model. Consequently, an ORSAT Tutorial was hosted by the Orbital Debris Program Office at NASA Johnson Space Center on June 26. This meeting was well-attended with representatives from NASA Headquarters, Goddard Space Flight Center, Marshall Space Flight Center, Langley Research Center, and the Jet Propulsion Laboratory. The next tasks involve planned revisions to NPD 8710.3 and NSS 1740.14. ♦

DoD-NASA Orbital Debris Working Group Meeting

The DoD-NASA Orbital Debris Working Group met in Colorado Springs, CO on 17 April 2001. The DoD delegation was led by Col. Theresa R. Clark, Chief, USAF Space Control Division and the NASA delegation was led by Nicholas Johnson, Chief Scientist, NASA Orbital Debris Program Office.

From the NASA point of view, one of the most important decisions to come from the meeting was the decision by HQ AFSPC/DOY to continue to program funding for Haystack/HAX data collection beyond when the current MOA expires in FY2004. Haystack has been the primary source of debris environment measurements in the 1-cm. size range.

The Joint NASA-DoD Work Plan on Orbital Debris was last revised in July 1999, and

no changes to the Work Plan were made in 2000. As a result of various discussions, the group agreed that the 2001 Work Plan review should include a rewrite of the document to more clearly define the purpose of the working group, remove outdated information, and delete several redundant work plan tasks. NASA agreed to provide a draft updated work plan by May 30th, and requested inputs from all working group members.

The current workplan was reviewed and several tasks were closed due to completion.

NASA summarized recent activities including: 1) the study it conducted for the Naval Warfare Systems Command which provided simulated two-line element (TLE) sets for the planned Naval Space Surveillance fence up-

grades, 2) the current status of its radar and optical measurements, 3) upgrades to the NASA Orbital Debris Engineering Model, ORDEM2000, and 4) upgrades to the Debris Assessment Software (DAS).

DoD summarized recent activities including: 1) plans for upgrading/modernizing the Naval Space Command Fence, 2) operations at the Cobra Dane radar and cost estimates for full time, full power operation, 3) status of the Ground Based Radar-Prototype (GBR-P) X-band radar at Kwajalein, and 4) implementation of mitigation guidelines in the DoD.

The next meeting is tentatively scheduled for the first quarter of 2002 at NASA's Johnson Space Center in Houston, Texas. ♦



Upcoming Meetings

29 July - 3 August 2001: *46th Annual Meeting of The International Society for Optical Engineering (SPIE)*, San Diego, California. The technical emphasis of the International Symposium on Optical Science and Technology is to create global forums that provide interaction for members of the optics and photonics communities, who gather to discuss the practical science, engineering, materials, and applications of optics, electro-optics, optoelectronics, and photonics technologies. This symposium will contain 84 conferences covering the technology areas of Lens and Optical System Design, Photonic Materials, Devices, and Circuits, Image Analysis and Communications, Radiation Technology, and Remote Sensing. Papers on debris will be presented under the Remote Sensing heading

and the Dual-Use Technologies for Space Surveillance and Assessments II subheading. More information can be found at <http://spie.org/conferences/Programs/01/am/>.

10-14 September 2001: *The 2001 AMOS Technical Conference*, Maui, Hawaii. The conference will highlight the resources and capabilities of the Maui Space Surveillance System (MSSS), and cover a broad range of related work. The technical program includes but is not limited to: laser propagation and laser radar, imaging, astronomy, small and autonomous telescope systems, adaptive optics, high performance computing, and orbital debris. More information on the conference can be found at <http://ulua.mhpc.af.mil/AMOS2001/index.html>.

html.

1-5 October 2001: *52nd International Astronautical Congress*, Toulouse, France. The theme for the congress is "Meeting the Needs of the New Millennium". The objective is to promote further exchanges between all the participants concerning scientific research, space activity applications and perspectives to meet the needs of society for the new millennium. Technical programs include three debris sessions: "Measurements and Modeling of Space Debris and Meteoroids," "Breakups, Risk Analysis and Protection," and "Mitigation Measures and Standards." Thirty papers will be presented in the three sessions. More information can be found at <http://www.iaf2001.org>.

INTERNATIONAL SPACE MISSIONS

April - June 2001

International Designator	Payloads	Country/ Organization	Perigee (KM)	Apogee (KM)	Inclination (DEG)	Earth Orbital Rocket Bodies	Other Cataloged Debris
2001-013A	MARS ODYSSEY	USA	HELIOCENTRIC			2	0
2001-014A	EKRAN 21	RUSSIA	35770	35811	1.8	1	1
2001-015A	GSAT 1	INDIA	33780	35768	0.8	1	0
2001-016A	STS 100	USA	378	404	51.6	0	0
2001-017A	SOYUZ-TM 32	RUSSIA	368	390	51.6	1	0
2001-018A	XM-1	USA	35785	35788	0.0	1	0
2001-019A	PAS 10	USA	35785	35789	0.0	2	1
2001-020A	USA 158	USA	ELEMENTS UNAVAIL.			2	0
2001-021A	PROGRESS-M1 6	RUSSIA	374	397	51.6	1	0
2001-022A	COSMOS 2377	RUSSIA	166	267	67.1	1	0
2001-023A	COSMOS 2378	RUSSIA	964	1010	82.9	1	0
2001-024A	INTELSAT 901	ITSO	35783	35791	0.1	1	0
2001-025A	ASTRA 2C	LUXEM.	35775	35798	0.1	2	1
2001-026A	ICO F2	NEW ICO	10104	10126	45.0	1	0

ORBITAL BOX SCORE

(as of 30 June 2001, as catalogued by US SPACE COMMAND)

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
CHINA	33	331	364
CIS	1329	2543	3872
ESA	29	262	291
INDIA	21	6	27
JAPAN	67	46	113
US	996	2883	3879
OTHER	257	28	285
TOTAL	2732	6099	8831

Orbital Debris Information

NASA Johnson Space Center:

<http://www.orbitaldebris.jsc.nasa.gov>

NASA White Sands Test Facility:

<http://www.wstf.nasa.gov/hypervl/debris.htm>

NASA Marshall Space Flight Center:

<http://see.msfc.nasa.gov/see/mod/srl.html>

NASA Langley Research Center:

<http://setas-www.larc.nasa.gov/index.html>

University of Colorado:

http://www-ccar.colorado.edu/research/debris/html/ccar_debris.html

European Space Agency:

<http://www.esoc.esa.de/external/mso/debris.html>

Italy:

<http://apollo.cnuce.cnr.it/debris.html>

United Nations:

<http://www.un.or.at/OOSA/spdeb>

NASA Hypervelocity Impact Technology Facility:

<http://hitf.jsc.nasa.gov>

Orbital Debris Documents

National Research Council, "Orbital Debris – A Technical Assessment":

<http://www.nas.edu/cets/aseb/debris1.html>

National Research Council, "Protecting the Space Station from Meteoroids and Orbital Debris":

<http://www.nas.edu/cets/aseb/statdeb1.html>

National Research Council, "Protecting the Space Shuttle from Meteoroids and Orbital Debris":

<http://www.nas.edu/cets/aseb/shutdeb1.html>

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Hubble Space Telescope Solar Array Hypervelocity Impact Tests, Cont'd

(Continued from page 3)

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3. Gerlach, L., 1994, *Post-flight Investigation Programmes of Recently Retrieved Solar Generators*, 13th Space Photovoltaic Research and Technology Conference, 14-16 June 1994, NASA Lewis Research Center, Cleveland, Ohio. ❖